V. *Some Obſervations on the Heat of Wells and Springs in the Iſland of* Jamaica, *and on the Temperature of the Earth below the Surface in different Climates. By* John Hunter, *M. D. F. R. S.; communicated by the Hon.* Henry Cavendiſh, *F. R. S.*

Read December 20, 1787.

TO THE HON. MR. CAVENDISH.

SIR,

THE following obſervations on the heat of ſprings and wells, and their application towards determining the mean temperature of the earth in different climates, were ſuggeſted by you in ſome converſation on that ſubject, previous to my going to Jamaica in 1780. If you think them deſerving the attention of the Royal Society, I muſt beg the favour of you to lay them before that learned Body.

I have the honour to be, &c.

JOHN HUNTER.

Charles-ſtreet,
Dec. 11, 1787.

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THE great difference between the temperature of the open air, and that of deep caverns or mines, has long been taken notice of, both as matter of curiofity and furprize. After thermometers were brought to a tolerable degree of perfection, and meteorological regifters were kept with accuracy, it became a problem, to determine what the caufe was of this difference between the heat of the air, and the heat of the earth; for it was foon found, that the temperature of mines and caverns did not depend upon any thing peculiar to them; but that a certain depth under ground, whether in a cave, a mine, or a well, was fufficient to produce a very fenfible difference in the heat. In obfervations of this kind, there was perhaps nothing more ftriking, than that the heat in fuch caves was nearly the fame in fummer and winter; and this even in changeable climates, that admitted of great variation between the extremes of heat in fummer, and cold in winter. There is an example of this in the cave of the Royal Obfervatory at Paris. The explanations, which have been attempted of this phænomenon, have turned chiefly upon a fuppofition, that there was an internal fource of heat in the earth itfelf, totally independent of the influence of the fun *. M. DE MAIRAN has beftowed much labour on this fubject, and by obfervation and calculation is led to conclude, that of the 1026° of heat (by REAUMUR's fcale), which he finds to be the heat of fummer at Paris, 34°,02 only proceed from the fun, and the remaining 991°,98 from the earth, by emanations of heat from the center †. The proportion therefore of heat derived from this latter fource is to that of the fun, as 29,16 to 1. It muft be evident, that an hypothefis of this kind, which renders the influence of the fun of fmall account, is directly contrary to the general

* Vid. MARTINE's Effays, p. 319.

† Memoir. de l'Acad. des Sciences, An. 1719 et 1765.

experience

experience and conviction of mankind. Without entering, however, into any discussion of the *data* from whence M. DE MAIRAN draws his conclusions, it will be more satisfactory to consider what the effect of the operation of those laws of heat, with which we are acquainted, would be.

And first, it is well known, that heat in all bodies has a tendency to diffuse itself equally through every part of them, till they become of the same temperature. Again, bodies of a large mass are both cooled and heated slowly. Besides the mass of matter, there are two other considerations of much importance in the slow or quick transmission of heat through bodies; these are their different conducting powers, and their being in a state of solidity or fluidity. The conducting powers of heat are well known to be very various in different bodies; nor are they hitherto reducible to any law, depending either upon the density, or chemical properties of matter. Metals of all kinds are good conductors of heat, while glass, an heavy, solid, homogeneous body, is an extremely bad conductor, even when a metallic calx enters largely into its composition, as in flint-glass. A state of fluidity greatly promotes the diffusion of heat; for a body in a fluid state, by the particles moving readily among each other from their different densities or other causes, mixes the warm and cold parts together, which occasions a quick communication of heat. To apply these observations to the present subject; the surface of the earth being exposed to the great heats of summer, and the colds of winter, or more properly the low degree of heat of winter, will receive a larger proportion of heat in the former season, and a smaller in the latter; and being further of a large mass, and of a porous and spongy substance, and therefore not quickly sensible to small variations of heat, it will become of a mean temperature at a certain depth, between the heat of summer,

and the cold of winter, provided it contain no internal ſource of heat within itſelf. This concluſion is ſtrictly agreeable to the experiments and obſervations hitherto made, in heating and cooling bodies, or in mixing portions of matter of the ſame kind of different temperatures *. Water, though in a large maſs, follows in ſome degree the heat and cold of our ſummer and winter, from the mobility of its parts occaſioning a more ſpeedy diffuſion of heat. Air is quickly ſuſceptible of heat, and from the expanſions produced in it, and conſequent motions in the whole maſs, the temperature is ſoon rendered uniform.

The changes in the heat of the air are what we have meaſured, and we are to be underſtood to ſpeak of them, when we talk of the temperature of ſummer and of winter. It may be aſked then, is the heat of the ſun firſt communicated to the air, and thereby to the earth? No, the air is ſuſceptible of a very ſmall degree of heat from the rays of the ſun paſſing through it; for it is well known, they produce no heat in a tranſparent medium, and conſequently, that the air is only ſo far heated as it differs from a medium that is perfectly tranſparent. The heat produced by the rays of the ſun bears a proportion to their number, their duration, and their falling more or leſs perpendicularly; and it takes place at the points where they ſtrike an opaque and non-reflecting ſurface. The ſurface of the earth may therefore be conſidered as the place, from whence the heat proceeds, which is communicated to the air above, and the earth below. That this is really the caſe is evident from the ſuperior degree of heat, produced by the action of the rays of the ſun upon an opaque body, which will often be heated to 150° (FAHRENHEIT), while the temperature of the air is not above 90° †. It may ſeem, therefore, that to meaſure the heat communicated

* Vid. DE LUC Modifications de l'Atmoſphere, Vol. I. p. 285.

† MARTINE's Eſſays, p. 309.

to the earth, it ſhould be done at the ſurface, where the action of the rays immediately takes place. But though the heat be produced at the ſurface, it is communicated freely to the air as well as the earth; and though the apparent intenſity of heat be greater in the earth, from the rays of light acting for a longer time upon the ſame parts of matter, yet there is little doubt that much the greater part is carried off by the air, which as it is heated flies off, and allows a freſh portion of cold air to come in contact with the heated ſurface. But ſtill it is immaterial, whether the heat of the ſun be excited more in the earth or in the air; for whichever has the larger proportion will in the end communicate a part to the other, and ſo reſtore the balance. The ſame obſervation applies to ſuch cauſes of cold as may operate at the ſurface of the earth, as evaporation, and that taken notice of by Mr. WILSON *. The air, therefore, near the ſurface of the earth will ſhew by a thermometer in the ſhade nearly, if not exactly, the ſame degree of heat that the ſun communicates to our terreſtrial globe; and if a mean of the heats thus ſhewn be taken for the year round, and we penetrate into the earth to that depth, that it is no longer affected either by the daily, monthly, or annual variations of heat, the temperature at ſuch depth ſhould be equal to the annual mean above mentioned. To aſcertain this with the utmoſt preciſion, it muſt be obvious, that numerous obſervations ſhould be made every day, correſponding to the frequent changes of temperature, which are known to happen in the courſe of the twenty-four hours in all climates; and upon theſe a daily mean ſhould be taken, and the annual mean deduced therefrom. This has not yet been done, but where we have obſervations from which a mean temperature can be deduced with any degree of certainty, it will be found not to differ greatly from

* Vid. Phil. Tranſ. Vol. LXX. p. 451. and Vol. LXXI. p. 386.

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the heat of deep caves, or wells in the ſame climate. If further experience and obſervation ſhould confirm the above opinions, it will be attended with this advantage, that we ſhall be poſſeſſed of an eaſy and ready method of aſcertaining the mean temperature of any climate; which, with a few obſervations of the extremes of heat and cold at particular ſeaſons, will teach us as much of the country, with regard to heat and cold, as the meteorological obſervations of ſeveral years.

For obtaining the temperature of the earth the beſt obſervations are probably to be collected from wells of a conſiderable depth, and in which there is not much water. Springs iſſuing from the earth, although indicating the temperature of the ground from whence they proceed, are not ſo much to be depended upon as wells; for the courſe of the ſpring may be derived from high grounds in the neighbourhood, and it will thence be colder; it may run ſo near the ſurface as to be liable to variations of heat and cold from ſummer and winter; or it may be expoſed to local cauſes of heat in the bowels of the earth. Wells ſeem alſo better than deep caverns, for the apertures to ſuch are often large, and may admit enough of the external air to occaſion ſome change in their temperature. Wells are not, however, to be met with in all places, and in that caſe we muſt remain ſatisfied with the temperature of the ſprings.

The following obſervations were made in the Iſland of Jamaica, where there are flat lands in many parts towards the coaſt, but all the interior part of the country is mountainous. The heat is greateſt in the low lands, and decreaſes as you aſcend the mountains. The town of Kingſton is ſupplied with water from wells. The ground on which it ſtands riſes with

a gentle aſcent as you recede from the ſea. In the low part of the town the wells are but a few feet deep, and many of them brackiſh. The heat of the water in ſome of them I have found as high as 82°; but they were evidently too near the ſurface not to be affected by the heat of the ſeaſons. As you aſcend, the wells are deeper, and the temperature is nearly 80° in all of them. What variations there are, come within one degree, that is, half a degree leſs than 80°, or half a degree more. They are of different depths, and ſome not leſs than 100 feet; though, after they are of half that depth, the temperature is nearly uniform. At the *Governor's Pen*, which is alſo in the low part of the country, a well, which is above 60 feet deep, is 79½°. There is a well at Half-way-Tree, 243 feet deep, which is 79°. Half-way-Tree is two miles from Kingſton, with a very gentle aſcent. Near Rock-Fort is a ſpring, immediately at the foot of the long mountain, which throws out a great body of water; the heat of it is 79°. All the places mentioned are but very little above the level of the ſea, probably not more than the depth of the wells at the reſpective places; for near Kingſton there are ſprings that appear juſt below the water-mark of the ſea, and thoſe that ſupply the wells are probably upon the ſame level.

The temperature of the air at Kingſton admits but of ſmall variation. The thermometer, at the hotteſt time of the day, and during the hotteſt ſeaſon of the year, ranges from 85° to 90°; in the cooleſt ſeaſon, and obſerved about ſun-riſe, which is the coldeſt time in the twenty-four hours, it ranges from 70° to 77°. I have ſeen it once as low as 69°, and two different times as high as 91°. The annual mean temperature cannot, therefore, either much exceed, or fall much ſhort of, 80°, as indicated by the wells.

The following ſprings were examined with much accuracy by the Hon. Mr. SEWELL, Attorney General of the Iſland.

Ayſcough's ſpring, on the road from Spaniſh Town to Puſey's, in St. John's pariſh, 75°.

Puſey's ſpring, ſtill higher in the mountains, 72°¾.

A ſpring near the baracks at Points Hill in St. John's pariſh, 70°.

The thermometer in the ſhade at Puſey's, during part of the month of June, was found to range from 69°½ to 79°½. It was obſerved both late at night, and early in the morning before ſun-riſe.

The ſpring in Brailsford Valley, about ten miles above Spaniſh Town, is 75°. The ſpring at Stoney Hill is 71°. Theſe were examined by Mr. HOME.

Mr. WALLEN's houſe, at Cold Spring, ſtands the higheſt of any in the iſland. By a meaſurement, ſaid to have been made by Mr. M^c FARLANE, it is reported to be 1400 yards above the level of the ſea. On the road to it, and about a mile below Mr. WALLEN's houſe, there is a ſpring that iſſues from the ſide of the hill, of the temperature of 65°. Cold Spring, which gives a name to the place, is about fifty feet below the houſe, and the heat of it is 61°¾. The thermometer in the ſhade at Mr. WALLEN's houſe, for ſome days in the month of April, ranged from 57° to 67°. It may be remarked, that the higher the ſprings the colder they are; and, as far as a conjecture can be formed from ſo few obſervations, they would appear not to differ much from the mean temperature of their reſpective places *.

It will not be out of place to add ſome obſervations made in England, relative to the ſame ſubject. The wells in and

* The thermometers made uſe of were all made by Mr. RAMSDEN.

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about London are either of no great depth, or are full of water, which are both confiderable objections to their giving a mean temperature. The want of depth will make them fubject to the variations of the feafons; and a large quantity of water, even in a deep well, will take the temperature of the air more or lefs: for any change of temperature communicated at the furface will, from the fluidity of the water, be readily diffufed through the whole. I fufpect it is owing to this caufe, that the wells in the neighbourhood of Brighthelmftone vary from 50° to 52°, for thofe were the higheft that had moft water in them. My obfervations were made in fummer. Thefe wells are of various depths, from 15 to 150 feet. That which I always found the coldeft is not more than 22 feet deep; I never found its heat greater than 50°. It is near the beach, and is a tide well, that is, the water in it rifes and falls, and in fo doing does not correfpond exactly with the tides, but follows them with an interval of about three hours. At the loweft there is not more than a foot of water in it; and it may be confidered as a fubterraneous fpring running through the bottom of the well. There are in fact numerous fprings that break out upon the fand, a few feet above the low-water mark, which are doubtlefs the fame that fupply the wells. As we are not acquainted with any caufe that produces cold in the bowels of the earth, we muft neceffarily in every climate, confider the loweft degree of heat as approaching neareft to the mean temperature; and therefore we cannot conclude the mean temperature at Brighthelmftone to be more than 50°. The mean temperature of London is computed about 52°*; but Brighthelmftone is nearly fifty miles farther fouth than London, and is immediately upon the fea,

* KIRWAN's Temperature of different Latitudes, p. 73.

and muſt therefore be at leaſt as warm as London. It is evident, that the obſervations from which the mean is taken, muſt generally contain more of the extremes of heat than of cold, as the former happen in the day-time, and the latter in the night, in conſequence of which they will often eſcape notice. There is a table conſtructed by Dr. HEBERDEN *, expreſſing the heat in London for every month in the year, from a mean of ten years beginning with 1763, and ending with 1772. The mean temperature is given both at 8 A.M. and 2 P.M. There is further in the table, a column of the mean of the greateſt monthly colds in the night, obſerved during the ſame ten years by Lord CHARLES CAVENDISH, in Marlborough-ſtreet. There will not probably be any great error in conſidering the heat obſerved at 2 P.M. as the greateſt daily heat; and taking a mean btween the greateſt heats of the day, and greateſt colds of the night, they give 49°,196 for an annual mean, which is much lower than is commonly ſuppoſed. At the houſe of GEORGE GLENNY, Eſq. near Bromley, there is a well ſeventy-five feet deep, which I found in November 49°½. M. DE MAIRAN has given a table of the greateſt heats and greateſt colds obſerved at Paris for fifty-ſix years, beginning from 1701; and a mean of them is 10° above freezing, or 1010°, of REAUMUR's ſcale †. The temperature of the cave of the Obſervatory where thoſe obſervations were made, is 10°¼ above freezing, by the ſame ſcale of REAUMUR. There appears not therefore any neceſſity for an internal heat; on the contrary, it is matter of demonſtration, that were there any ſource of heat in the earth which was not equally in the air, the heat of the interior parts ought to be

* The Table alluded to follows this Paper.

† Mem. de l'Acad. des Sciences, An. 1765, p. 202.

higher

higher than a mean: and did the *central heat* bear as high a proportion to that of the ſun as M. DE MAIRAN alledges, the heat of the earth itſelf ought to be a great deal above the mean temperature of the air, which from obſervation there is no ground for believing. It is eaſy to ſee the ſource of M. DE MAIRAN's error; he has founded his calculations upon the ſcale of REAUMUR, and conſiders the degrees of his thermometer as marking the real proportions, and abſolute quantity of heat *. It is a matter that cannot be denied, that we know nothing of the abſolute quantities of heat; and that the degrees of our thermometers are only to be conſidered as a few of the middle links of a chain, the length of which we are totally ignorant of, and therefore in no condition to compare its proportional parts. It deſerves, however, to be remarked, that obſervations of a late date have ſhewn, that the notions of cold upon which REAUMUR's ſcale was conſtructed, and upon which M. DE MAIRAN's calculations are founded, are imaginary and without foundation †.

Hot ſprings and volcanos may be produced as proofs of the exiſtence of an internal ſource of heat in the earth; but their operation appears to be limited to a very ſmall extent, and ſcarcely deſerving of notice in the preſent diſcuſſion. It is no uncommon thing to find ſprings of the uſual temperature cloſe by hot ſprings; and no volcano, with which we are yet acquainted, appears to have raiſed the temperature of the country immediately adjoining to it.

The ſea admits of change of temperature more quickly than the earth, particularly near the ſhore. The mean heat of the ſea

* Vid. Memoir. de l'Acad. des Sciences, An. 1765, p. 143.

† Vid. Phil. Tranſ, Vol. LXXIII. p. *303. 303. and 329.

ſea at Brighthelmſtone, during the months of July, Auguſt, September, and October, was as follows:

July	$63^{\circ}\frac{1}{7}$
Auguſt	$63^{\circ}\frac{1}{2}$
September	58°
October	53°

The obſervations were made with a view to aſcertain the temperature of the ſea as a bath, and therefore the heat was taken about nine in the morning, and near the ſhore, the uſual time and place of bathing. The water gets hotter towards three o'clock in the afternoon, ſo that it not only follows the monthly, but even the daily changes of the temperature of the air. In the four months juſt mentioned, the extremes of heat and cold are conſiderable: I have ſeen it as hot as 71°, and as cold as 49°. In the month of Auguſt laſt, Sir HENRY ENGLEFIELD examined the heat of the ſea at the ſame time that I did, and we both found it 71°: it was about 4 P.M. of a very hot day. I may be allowed to remark, that ſea-bathing is a very different thing at different ſeaſons of the year, and requires an acquaintance with the variations of the temperature, to adapt it to particular caſes.

It were to be wiſhed, that the heat of wells and ſprings were examined at different ſeaſons of the year, in order to aſcertain the effect of ſummer and of winter upon them. The wells at New York are from 32 to 40 feet in depth, and Dr. NOOTH found them to have an annual variation of two degrees from 54° to 56°. There are few countries, in which the annual range of the thermometer is greater than at New York, and the neighbouring parts of America. In the ſummer it is often as high as 96°, and in winter it has been obſerved ſeveral degrees below the zero of FAHRENHEIT's ſcale.

We may, I think, from all the obſervations we are yet in poſſeſſion of, conclude, that there is at preſent no ſource of heat in the earth, capable of affecting the temperature of a country, which is not derived from the ſun; and that the earth, whatever changes of temperature it may be conjectured to have undergone in former periods, is now reduced to a mean of the heat produced by the ſun in different ſeaſons, and in different climates.